

Rapid Assessment of Reef Responses to Elevated Sea-Water Temperatures Caused by the El Niño Southern Oscillation (ENSO) Current System in Indian Waters

A Report Submitted to
Wildlife Conservation Society, New York

By
Rohan Arthur

Centre for Ecological Research and Conservation
Research Unit of the Nature Conservation Foundation
3076/5, IV Cross, Gokulam Park, Mysore 570 002, INDIA
www.ncf-india.org



Suggested Citation

Arthur, R. 1999. Rapid Assessment of Reef Responses to Elevated Sea-Water Temperatures Caused by the El Niño Southern Oscillation (ENSO) Current System in Indian Waters. CERC Technical Report #2, Centre for Ecological Research and Conservation, Mysore.

Acknowledgements: This survey enlisted the help, co-operation and kindness of so many people, that I am afraid that the narrow space of an acknowledgement cannot fulfill the debt I owe them.

- The Wildlife Conservation Society, and in particular Dr. Ullas Karanth, for responding more quickly than I could hope to my request for funds, and for being supportive throughout.
- The Gulf of Kutch Forest Department. Smita, Kunal, Natasha, Oovi, Rewanta, Adam and Ayesha, for being willing slaves and for making a difficult trip plenty of fun. Oomar bhai and his untrustworthy bark nearly killed us all more than once, but we love him nevertheless.
- The Lakshadweep Administration and Department of Science, Technology and Environment for providing every support. Mr. G. Srivastava, Chairman, LDCL, for his friendly ear and earnest concern. Dr. SI Koya for taking an active part in the survey, accompanying us into the field, and inspiring his Wardens and volunteers, to see the usefulness of our work. Madhu, who, with one encouraging and one disapproving eye, did his best to keep this leg of the survey on course. The chaps from Laccadives in Bombay, Shaukat and Haneefa, for paving the way, and ensuring the smoothest possible sailing in rough seas. Jason Rubens of the GCRMN for his support and comments at every stage of this survey. Dr. Timothy McClanahan and Dr. David Obura, sharing experiences, and offering advice.
- The Gulf of Mannar was a new reef location for me, and the trip would not have been possible without the help of Dr. AK Kumaraguru of Madurai Kamraj University and his students, particularly Jayakumar and Rajakumar. Roosevelt and his crew of able seamen were also helpful, directing us to good reef sites, and for ferrying us uncomplaining from reef to reef. Divya, Sridhar and Biddappa, for support when it was most needed. Madhu Katti and Kutti, and all at Wildlife Institute for helpful comments on the survey, and for encouragement throughout.

SUMMARY

The El Niño Southern Oscillation (ENSO), the warm water ocean current system that develops off the west coast of South America, elevating global ocean temperatures has, in the past, influenced the ecology of near-shore marine ecosystems, particularly coral reefs. Elevated Sea Surface Temperatures (SSTs), higher than 1°C above the seasonal average, can result in widespread bleaching events in scleractinian corals and other coelenterates with symbiotic photosynthetic algae. Recovery from this bleaching depends on the intensity of the ENSO event, and local conditions.

This study assessed the extent of bleaching in three reef regions in the country using rapid assessment methods. Data on substrate composition and coral genera were collected along 10m transects, and in 1m² quadrats. SST anomalies and duration was established using NOAA SST maps. The survey shows that bleaching had occurred in all reef regions studied. The reefs of the Gulf of Kutch showed an average of 10.7% coral affected by the bleaching, with only 1.9% coral cover completely bleached, the rest of it showing heat stress by loss of pigmentation. No apparent bleaching-related mortality of coral was observed in the Gulf of Kutch. In contrast the lagoon reefs of Lakshadweep, and the reefs of Mannar were severely influenced by the bleaching event; some 81.8% of the total coral cover was affected in Lakshadweep, and 89.2% in Mannar. Bleaching-related mortality was high in both these reefs (25.7% in the Lakshadweep, 23 % in Mannar), and a large proportion of coral still did not show signs of recovery. Several instances of bleached soft coral and sea anemones were also noted.

I present the potential implications of this mass bleaching event on the sustained conservation and management of Indian reef systems. I outline the possible ecological and socio-economic fall-outs of this mortality, and stress the need for strict, sustained reef monitoring. This is essential to keep track of further mortality, recovery of coral, and to detect any far-reaching changes to the functioning of the reef

INTRODUCTION

Disturbance ecologists have, for several years been both concerned and fascinated with large-scale disturbance events that frequently affect coral reefs (Glynn 1993, Connell 1997). Storms and unusually prolonged low tide events, *Acanthaster planci* outbreaks, white-band disease (WBD) plagues of coral, and seawater temperature elevation, all threaten coral and the reefs they inhabit. These events are showing both, that the reefs of the world are under severe threat, but also that they are surprisingly resilient to disturbance, and can recover from mass die-outs, with time, and intelligent management.

The El Niño: The El Niño Southern Oscillation (ENSO) of 1997-1998 created a near pan-tropical band of warm water, that is, till today affecting ocean systems around the world. While the El Niño always brings in its wake a spate of global climatic changes, and an inevitable host of ecological and economic disasters, the present event is perhaps the most severe in recorded history, and has already been implicated as the causative agent for the drought in the Philippines, the failure of rains in Indonesia, where forests continue to be devastated by fire, and in the torrential rains in North-America and parts of Africa. Perhaps the most direct impact of the ENSO however, is on marine and coastal

[†] This work was presented at the National Wildlife Seminar on Wildlife Conservation, Research and Management, Dehradun, August 10-13, 1998

ecosystems. Reports from locations around the tropics point to a developing global catastrophe for coral reef ecosystems of the world.

Bleaching: The most significant and noticeable result of temperature elevation in reef waters is a phenomenon known as bleaching, which is a rapid loss of pigmentation of coral, leading to a complete whitening of the colony. Bleaching is a generalised stress response of scleractinian coral, caused by the expulsion of the photosynthetic symbiont zooxanthallae by the polyp, or by a severe reduction in the photosynthetic activity of resident zooxanthallae (Kleppel *et al.* 1989). Zooxanthallae lend the coral its characteristic colour, and its expulsion in large numbers, reveals the true white colour of the coral polyp. Bleached coral regain photosynthetic algae when conditions improve, but if the stress is severe and prolonged, the coral often dies because of prolonged bleaching, and other secondary stresses (Brown 1997).

Causes of Bleaching: Elevated sea-water temperatures are perhaps the most important and widely reported cause of coral bleaching (Glynn 1993, Brown and Suharsono 1990), and it is often a normal, non-lethal response to seasonal variation in water temperatures (Gates 1990). Increased irradiance, reduced salinity, bacterial infection and decreased water temperatures have also been known to cause coral bleaching (Brown and Suharsono 1990, Kushmaro *et al.* 1996).

Mass Bleaching: Mass bleaching was first observed on the coral reefs of the Pacific in 1984 (Glynn 1991), and has since been noticed as a common phenomenon in reefs across the tropics. It appears to be well correlated with changes in Sea Surface Temperatures (SST's), and, in El Niño years, the frequency of bleaching events in coral reefs increase dramatically (Glynn and D'Croz 1990, Williams and Bunkley Williams 1990). The current ENSO has seen initial reports of coral bleaching and mortality from reefs in East Africa to the islands of the Pacific, and several programmes to monitor recovery and further mortality have already been set up.

Indian coral reefs have not received the same attention because of the lack of field researchers in coral reefs of the country. Reefs in India occur in patchy locations around the country; major reef areas exist in the Gulf of Kutch, the Lakshadweep, Mannar, and the Andaman and Nicobars. Coral presence and reef formation has also been reported in scattered locations along the west and east coasts of India (Bakus 1994, Pillai 1996). This survey was conducted to rapidly assess the impact of the current El Niño system on some of the coral reefs of India, to provide a minimum baseline from which further monitoring can be done. The survey was conducted on several islands of the Gulf of Kutch, the Lakshadweep and the Gulf of Mannar. The survey assessed bleaching related stress to corals, and quantified the amount of coral mortality already caused by the ocean warming.

STUDY AREAS

The Gulf of Kutch: Some 42 islands dot the southern lip of the Gulf of Kutch ([Figure 1](#)). The reefs that fringe these islands are atypical fringing reef formations, and are found primarily in the vast intertidal region of the Kutch. Coral survives in shallow tidal pools within the vast intertidal flats that characterise this coastline. Coral cover and diversity is low and patchy (Arthur 1995). Several of these reefs are recovering from large-scale coral

mining practised in the past. This region forms part of the Gulf of Kutch Marine Park and Sanctuary, but the anthropogenic pressures on this group of islands continues to be high (Patel 1985). Several polluting industries fringe the coastline, and development continues unabated, sometimes directly affecting reef areas, as in the case of the oil refineries that build their receiving pipelines through the reef. The survey was conducted in the reefs of Pirotan, Meetha Chusna, Ajad, and in Betu, a submerged reef close to Ajad. The islands were sampled between the 28th of April, 1998 and the 9th of May, 1998.

The Lakshadweep Islands: In the Western Indian Ocean, the Lakshadweep and Minicoy group of coral atolls ([Figure 2](#)), along with the Maldives and Chagos are an important biogeographic link for coral reefs. The archipelago comprises some 27 islands, ten of which are inhabited. The total land area of these islands is 32 km², and has among the highest population densities in the country (1922 people/km², Thangal 1994). The reefs enclose the islands in extensive lagoons and protect them from storm damage and other ravages of the sea. Diversity is high, and the islands share much of their fauna with the reefs of the Maldives, with some faunal affinity to the reefs of mainland India (Sheppard 1987). The onset of the monsoon and some particularly inclement weather in the open sea, made work possible only in the lagoon reefs of the Lakshadweep. The survey was conducted in the lagoons of Kavaratti and Kadmat between the 9th and 19th of June, 1998.

The Gulf of Mannar and Palk Bay: The islands of the Gulf of Mannar and Palk Bay are a series of shallow fringing uninhabited islands ([Figure 3](#)). The reef fauna is linked closely to Sri Lankan coral reefs. The south-eastern coast of India is heavily populated, and the dependence of local communities on marine resource is heavy. A high density of trawlers and boats ply these waters and the seas in this region appear to have a high nutrient influx. The reefs are used extensively for shell, algae, and sea cucumber collection. Corals are also mined illegally from many areas, adding to the pressures on the reefs of this coast (Bakus 1994, Pillai 1996). Bleaching surveys were conducted on the islands of Manauli Putti, Shingle, and Pumarichan in the Gulf of Mannar between the 7th and the 11th of July 1998.

METHODS

The purpose of this study was to rapidly assess reef responses to seawater temperature elevation. Several weeks had already past since SST anomalies had been noticed in these waters, and it was crucial to get all information with rapidity, to ensure that confounding factors did not invade in the analysis of the impact. Much mortality had already occurred in most reefs, and it becomes difficult to determine the cause of mortality accurately after a time.

The core of the sampling strategy was the Point Intercept Transect. This consists of a ten-metre line laid out along the substratum, data collected along this line as the number of 10-cm points intercepted by each benthic component under the line. Data was collected on coral at the genus and lifeform level. For a detailed description of the lifeform classification method, see English *et al.* (English *et al.* 1997). Coral affected by bleaching were classified in three ways:

Pale: The colony shows pale pigmentation. This is caused either by a partial loss of zooxanthallae or the lowering of photosynthetic content in the available zooxanthallae. With the snapshot nature of this sampling, it is impossible to determine whether the coral was bleached in the past and is now recovering, or is heading towards a more severe bleaching. In either case though, it is a sign of significant stress.

Bleached: The colony shows a brilliant white appearance, though the coral is not yet dead. Even completely bleached coral will have some zooxanthallae, but the density within each polyp will be severely reduced. If conditions remain stressful, these bleached coral often die.

Dead: Coral exposed to extensive bleaching eventually die because of bacterial infections and other stresses. Sediment rejection rates decrease, and an accumulation of sediment on the coral prompts the growth of turf algae that form a thin mat over the coral. Since this turf grows very quickly, it is often difficult to separate old coral death from post-bleaching mortality. To be conservative I classified coral in this category only if the layer of sediment and algae was visibly thin, and some traces of the bleached coral beneath could be seen. This provides an under-representation of the amount of coral death caused by bleaching, but it protects against doomsday prophesying.

Data on other substrate components (fleshy and coralline algae, sessile invertebrates, seagrass, and all abiotic components) were recorded along the transect. If other organisms showed signs of bleaching stress, this was also recorded.

In the Gulf of Kutch, the waters were too turbid to sample with transect methods because the waters clouded up within a few minutes of sampling. In these reefs, I estimated benthic cover in 1m² quadrats at every alternate metre along a 30m line. Data on the size and condition of each coral colony within the quadrat was estimated. Data was then pooled for each 30m line for analysis. Though data is not strictly comparable with the data from the Lakshadweep and Mannar, but it represents the field condition fairly accurately, and I present the data together. Data were analysed as proportions and frequencies along the transect line, and ANOVA's were used for comparisons.

Tracking the Anomaly: Sea Surface Temperatures (SSTs) greater than 1°C above the seasonal average are sufficient to cause significant bleaching in most coral (Brown 1997). Using satellite data, it is possible to record changes in regional waters of 0.25°C and above (Gleeson and Strong 1995). I used twice-weekly NOAA/NESDIS SST maps of the Indian Ocean (accessed from the NOAA website <<http://www.noaa.gov>>) to determine anomalous temperatures in Indian reef waters. I considered anomalous temperatures of 1°C or higher to be potential conditions for bleaching to occur (Brown 1997), and calculated the approximate number of days the reefs in the region had been subjected to this temperature anomaly.

RESULTS

The intertidal reefs of the Gulf of Kutch are characterised by sparse coral cover, 11.7% on average ([Table 1](#)). Old dead coral covered with turf and mud dominates the reef. Several species of macroalgae also contribute to the benthic community here, *Ulva*, *Sargassum*, *Caulerpa*, *Padina*, among the most common genera. Coral genera are limited; this study

recorded 11 genera of coral, restricted to massive and encrusting forms, dominated by *Favites*, *Porites* and *Platygyra*.

In contrast the lagoon reefs of the Lakshadweep, had a much higher coral cover, and about 14.9% coralline algal cover. Eighteen genera of coral were recorded in Kavaratti and Kadmat lagoons, *Porites*, branching *Acropora* and *Pavona* being the most abundant ([Table 2](#)).

The shallow reefs of the Gulf of Mannar had 33.6% coral cover, and a large proportion of old dead and turfed coral (32%). *Montipora*, tabular *Acropora* and *Porites* were the most dominant of the 12 genera recorded in Mannar reefs.

Bleached coral was encountered in all reefs surveyed. The Lakshadweep and Mannar reefs were most severely affected by the bleaching; more than 80% of the coral cover in the Lakshadweep, and nearly 90% of the coral in the Gulf of Mannar showed signs of bleaching stress ([Table 3](#)). Between 30 and 40 percent of the coral in these reefs were severely bleached, and more than 20% dead in bleaching related stress, in both reef areas.

The reefs of the Gulf of Kutch in contrast, seemed to be much less severely affected than the other reef areas. No obvious bleaching related death was observed in the seven reefs surveyed, and only 1.92% of the coral was bleached severely.

The differences in bleaching correlate well with the number of SST anomaly days recorded on satellite imagery, before the survey dates ([Table 3](#)). The Gulf of Kutch was sampled before abnormal mean SSTs were noticed in the gulf. In contrast the reefs of Lakshadweep had already experienced at least 78 days of elevated temperatures before this sampling, and the Gulf of Mannar, at least 99 days, temperatures rising to as much as 3°C above seasonal averages.

Coral lifeforms showed a differential response to coral bleaching in Lakshadweep and the Gulf of Mannar ([Figure 4](#)). While solitary Fungiids appeared indifferent to the rise in temperatures, Tabular, Branching and Massive corals were significantly affected by the bleaching in both reef areas. Encrusting coral show conflicting responses in both reef areas, being largely unaffected in the Lakshadweep (71.1% healthy coral), but severely bleached in the Gulf of Mannar (6.5% healthy coral). Part of the reason for this difference is that the encrusting coral in the Gulf of Mannar was monogenerically *Montipora*, which appeared to be badly affected by the bleaching in both reef areas. Several genera showed encrusting lifeforms in the Lakshadweep Islands, dominated by *Pavona*, which appeared largely unaffected by the anomalous temperatures.

DISCUSSION

The present survey indicates that the reefs studied are all undergoing bleaching stress, related to sea-surface temperature rise caused by the 1997-1998 El Niño. The Lakshadweep and Mannar reefs have been most severely affected, with large-scale mortality in both reef areas. It is difficult to determine from a rapid study if the coral died directly as a result of bleaching, or were killed by secondary stresses. In all probability, the observed death was a result of synergistically acting disturbances – heavy bleaching reducing the coral's ability to reject sediment build up, and resist the growth of

turf algae (Glynn 1993, Brown 1997). The Southwest monsoons could also have played a significant role in making waters more turbid, increasing suspended sediment levels in the water.

The bleaching reported appears to be correlated with rises in ocean temperature. Both, the duration, as well as the intensity of this rise contributes to the bleaching event. Satellite imagery gives a good overview of temperature conditions over a large area of the ocean, and is very useful in tracking changes in temperature over time. Ground truthing has shown that the smallest change the satellite can record is a 0.25°C rise in temperature, and the maximum error of this measurement may be as high as 0.5°C (Gleeson and Strong 1995). However, in the absence of continuous and reliable field data from reefs in India, the NOAA/NESDIS images are still the most useful and accurate means of gaining a comprehensive picture of the El Niño anomaly in Indian seas.

Levels of bleaching stress encountered correlate well with the number of days these reef areas were exposed to abnormal temperatures. It is important to note that abnormal temperatures continued to persist for at least four weeks after the survey dates. This survey, carried out while anomalous temperature conditions were still active, does not reflect the full extent of the damage caused by the bleaching event. From initial reports of subsequent observations on the reef, it is apparent that the reefs have deteriorated further, and that bleaching conditions are extremely widespread in these reef areas (Jason Rubens, pers. comm.).

The causal mechanisms of coral bleaching are not fully understood, nor conclusively proved (Glynn 1993). The evidence for seawater temperature rise being chiefly responsible for bleaching is largely circumstantial, and it is not possible to discount the influence of other stressing agent in the bleaching and death of the corals in these areas. Both the Gulf of Mannar and Lakshadweep have problems of high nutrient contents in their waters, besides a hosts of other anthropogenic disturbances (Bakus 1994, Pillai 1996). High levels of nutrients and bacterial infections have both been implicated as causal agents in coral bleaching (Glynn 1993, Kushmaro *et al.* 1996), and may facilitate the proliferation of fleshy algae, and coral bioeroders (Cuet *et al.* 1988, Hallock 1988, Eakin 1992, Gabric and Bell 1993). These stresses however are chronic, and are not likely to cause sudden intense mass bleaching as reported here. They could still be important agents of coral stress, lowering the disease-resistance of the coral, and exacerbating mortality in bleached coral.

The Gulf of Kutch, in contrast with the other reef areas surveyed, did not seem to be as badly affected by the bleaching, with 10.7% of the coral showing signs of bleaching. Very little obvious mortality could be ascribed to bleaching, and it is possible to suggest, that the bleaching encountered in the Gulf of Kutch was normal, related to a seasonal rise in ocean temperatures, before the onset of the monsoon. Temperatures in the intertidal reefs of the Gulf of Kutch commonly rise to as high as 36°C, and higher in reef areas during summer (Arthur 1995), and it is conceivable that coral species here are adapted to such seasonal temperature fluctuations (Gates 1990). It has also been suggested that for such high-latitude reef locations, bleaching may not be as significant a disturbance, since wide temperature variations are common at these latitudes (Cook *et al.* 1990). However, SST anomalies were not recorded in the Kutch waters till after the present survey was conducted, and it is possible that the sampling picked up only the start of a bleaching event in the Gulf of Kutch. A study conducted in 1995, estimating benthic cover in the

Gulf of Kutch, reported between 1.2% and 1.4% of the coral bleached in the summer months before the monsoons (Arthur 1995), indicating that the bleaching reported in this survey is considerably higher than normal summer bleaching. Even below bleaching thresholds, elevated temperatures have significant impacts on coral health, retarding coral growth and reproduction (Jokiel and Coles 1990).

Implications for Conservation:

It is difficult to predict how Indian reefs will respond to a large-scale die-out of coral without a reliable baseline, and with no sustained monitoring in any reef area in the country. Mass bleaching of this intensity has not been reported before from Indian reefs in previous El Niño years. From studies done elsewhere, it has been shown that reefs subjected to large-scale bleaching disturbances, may take 5 to 10 years to recover (Brown and Suharsono 1990, Connell 1997). Individual colonies may take up to five months to recover from bleaching (Bunkley Williams *et al.* 1991), and several species may go locally extinct in the process (Glynn and de Weerd 1991). Bleached coral suffer from lowered growth rates, and their reproduction potential is also severely affected (Goreau and Macfarlane 1990, Szmant and Gassman 1990). This could mean a considerable retardation in reef production. Brown and Suharsono (Brown and Suharsono 1990) demonstrate that five years after a major bleaching event, only 50% of the coral cover had recovered.

More subtle community changes are also likely to occur in bleached reefs. (Eakin 1992) reports increases in urchin densities in mass-bleached reefs, leading to the potential of further coral death through spine abrasion and erosion. Fleishy algae, potential competitors of coral, are also benefited by this coral death, and, presumably by shading the coral, can retard coral growth (Sheppard 1988). The effects of bleaching on other reef organisms, such as fish has not been well studied. Several species of fish and invertebrates, dependent on coral for shelter, camouflage and food will be the most badly affected, while several herbivorous fish, could likely see population increases in the wake of large-scale coral death (Eakin *et al.* 1989). Omnivorous fish numbers have been shown to rise opportunistically with coral bleaching, as previously well-hidden invertebrates were exposed. Whether these translate into more permanent changes in reef communities has not yet been demonstrated. Lowered coral resistance could also increase coral bioeroder numbers, considered one of the primary factors controlling post-bleach recovery in coral (Scott *et al.* 1988).

The mass bleaching of coral may portend a global disaster in the making, but it will most profoundly affect people at a more regional scale. Local communities are dependent on these reefs for their livelihood, supporting artizanal and bait fishery, as a source of ornamental products, and cheap construction material. Mass bleaching and its subsequent fallouts could spell a major problem for these reef based cottage industries and sustenance fishery. Major reef destruction for tiny atoll islands like the Lakshadweep, could be disastrous, increasing coastal erosion, and leaving them unprotected from storms and cyclones. Tourism in reef areas is also likely to decline, as the aesthetic experience of the reef that attracts the tourist, is replaced by dead remnant reefs.

While anomalous SST-induced bleaching was perhaps the primary cause of death implicated in this study, much mortality was most likely a result of anthropogenic stresses such as nutrient enrichment and sedimentation, working synergistically with elevated temperatures (Brown 1997). This points to a much longer-term problem of

rational coral reef management for Indian reefs. Marine conservation has not had a long history in India, and many terrestrial paradigms still dominate the management of marine reserves. Very little active management has actually been carried out in Indian waters – managers content with establishing areas of no-use (National Parks) and restricted use (Sanctuaries). This simplistic planning is both difficult to implement in the field, and does not tackle the much larger issues of reef decline that more often than not, have their roots far outside these ‘protected’ areas. The stresses that affect coral reefs most significantly today are insidious in nature, and, without constant *in situ* monitoring, it is impossible to track gradual changes in coral reef health. This basic knowledge is crucial if rational and planned management has to be effected in Indian reef waters, with clearly defined conservation goals, and reef-sensitive approaches to management.

Monitoring programmes and research:

In the absence of long-term monitoring of coral reefs, and the sparse information available on Indian coral reefs, it is difficult to make well-supported quantitative statements about the effect of the current bleaching event on the coral reefs of the country. This survey suffers naturally from the lack of a reliable baseline in time, with which to compare cover values for coral and other benthic components. In isolation, it may be a misleading snapshot of the health of the reef. What is apparent however, is that, at the time of the survey, large-scale coral stress and death was occurring, coincident with an anomalous rise in ocean temperatures. Within three months of the anomaly, between 80 and 90% of the coral was bleached or dead in the Lakshadweep and Mannar. It is imperative that a sustained monitoring of the reefs be initiated in the wake of this bleaching event. This is important to track recovery in reef areas, and to keep a pulse on any changes in reef community structure that could take place. Several easily applicable techniques for reef monitoring have been developed (English *et al.* 1997), which require moderate amounts of training. The Lakshadweep Island administration for instance has begun a programme of instituting posts of Honorary Environment Wardens, engaging local youth in environmental awareness programmes. Working in tandem with a local dive operation, some of these wardens are being equipped with diving skills, so that they can be effectively used in monitoring programmes. Initiatives like this are extremely promising, and could point to a new paradigm of community involvement in marine conservation in India.

This survey contributed to this programme by training a group of volunteers on both Kadmat and Kavaratti, in simple estimation techniques for reef monitoring. This was done in conjunction with the Department of Science, Technology and Environment. The trainees became reasonably proficient in collecting information on coral at a simplified life-form level after a few sessions of standardisation in the field. It is hoped that because of the institutional involvement, this initiative would retain its momentum, and a sustained monitoring process could begin in the Lakshadweep. In the Gulf of Mannar, I also attempted to train three post-graduate students of Madurai Kamraj University working in the area, in basic reef monitoring techniques. Again it is hoped, that this initiative will be followed by continued monitoring so that recovery from this mass bleaching can be effectively tracked.

REFERENCES

- ARTHUR, R. 1995. Disturbance and coral community structure in the intertidal coral reefs of the Southern Gulf of Kutch. Msc Thesis. Wildlife Institute of India.
- BAKUS, G. J., editor. 1994. Coral reef ecosystems. Oxford and IBH, New Delhi.
- BROWN, B. 1997. Coral Bleaching: Causes and Consequences. Proceeding of the 8th International Coral Reef Symposium: 1:65-74.
- BROWN, B., AND E. SUHARSONO. 1990. Damage and recovery of coral reefs affected by EL Nino related seawater warming in the Thousand Islands, Indonesia. *Coral Reefs* **8** (4):163-170.
- BUNKLEY WILLIAMS, L., J. MORELOCK, AND E. J. J. WILLIAMS. 1991. Lingering effects of the 1987 mass bleaching of Puerto Rican coral reefs in mid to late 1988. *Aquatic Animal Health* **3** (4):242-247.
- CONNELL, J. H. 1997. Disturbance and recovery of coral assemblages. Proceeding of the 8th International Coral Reef Symposium 1:9-22.
- COOK, C. B., A. LOGAN, J. WARD, B. LUCKHURST, AND C. J. J. BERG. 1990. Elevated temperatures and bleaching on a high latitude coral reef: The 1988 Bermuda event. *Coral Reefs* **9** (1):45-49.
- CUET, P., O. NAIM, G. FAURE, AND J. Y. CONAN. 1988. Nutrient-rich groundwater impact on benthic communities of La Saline fringing reef (Reunion Island, Indian Ocean): Preliminary results. Proceedings of the 6th International coral reef symposium, Townsville, Australia: 2:207-212.
- EAKIN, C. M. 1992. The 1982-1983 El Nino: Impact of eastern Pacific reef carbonate budgets and implications for severe bleaching disturbances. *Pacific Science* **46** (3):377.
- EAKIN, C. M., D. B. SMITH, P. W. GLYNN, L. D'CROZ, AND J. GIL. 1989. Extreme tidal exposures, cool upwelling and coral mortality in the eastern Pacific (Panama). Association of Marine Laboratories of the Caribbean, 22nd Annual Meeting Abstracts.
- ENGLISH, S., C. WILKINSON, AND V. BAKER, editors. 1997. Survey manual for tropical marine resources, 2nd Edition. Australian Institute of Marine Science, Townsville.
- GABRIC, A. J., AND P. R. F. BELL. 1993. Review of the effects of non-point nutrient loading on coastal ecosystems. *Australian Journal of Marine and Freshwater Research* **44**(2): 261-283.
- GATES, R. D. 1990. Seawater temperature and sublethal coral bleaching in Jamaica. *Coral Reefs* **8** (4):193-197.
- GLEESON, M. W., AND A. E. STRONG. 1995. Applying MCSST to coral reef bleaching. *Advanced Space Research* **16** (10):151-154.
- GLYNN, P. W. 1991. Coral reef bleaching in the 1980's and possible connections with global warming. *Trends in Ecology and Evolution* **6** (6):175-179.
- GLYNN, P. W. 1993. Coral reef bleaching: Ecological perspectives. *Coral Reefs* **12** (1):1-17.
- GLYNN, P. W., AND L. D'CROZ. 1990. Experimental evidence for high temperature stress as the cause of El Nino-coincident coral mortality. *Coral Reefs* **12**:1-17.
- GLYNN, P. W., AND W. H. DE WEERDT. 1991. Elimination of two reef-building hydrocorals following the 1982-83 El Nino warming event. *Science Wash.* **253** (5015):69-71.
- GOREAU, T. J., AND A. H. MACFARLANE. 1990. Reduced growth rate of *Montastrea annularis* following the 1987-1988 coral bleaching event. *Coral Reefs* **8** (4):211-215.
- HALLOCK, P. 1988. The role of nutrient availability in bioerosion: Consequence to carbonate buildups. *Paleogeography, Paleoclimatology, Paleoecology* **63** (1-3):275-291.
- JOKIEL, P. L., AND S. L. COLES. 1990. Response of Hawaiian and other Indo-Pacific reef corals to elevated temperature. *Coral Reefs* **8** (4):155-162.

- KLEPPEL, G. S., R. E. DODGE, AND C. J. REESE. 1989. Changes in pigmentation associated with the bleaching of stony corals. *Limnology and Oceanography* **34** (7):1331-1335.
- KUSHMARO, A., Y. LOYOLA, M. FINE, AND E. ROSENBERG. 1996. Bacterial infection and coral bleaching. *Nature* **380** (4):396.
- PATEL, M. I. 1985. Calcareous sand mining from beaches and littoral areas in the Gulf of Kutch, Gujarat and their possible deleterious effects on marine life. *Proceedings of the Symposium on Endangered Marine Animals and Marine Parks* **3**:41.
- PILLAI, C. S. G. 1996. Coral reefs of India, their conservation and management. Pages 16-31 in N. G. Menon and C. S. G. Pillai, editors. *Marine biodiversity conservation and management*. CMFRI, Cochin.
- SCOTT, P. J. B., M. J. RISK, AND J. D. CARRIQUIRY. 1988. El Nino, bioerosion and the survival of East Pacific reefs. *Proceedings of the VIth International Coral Reef Symposium, Townsville* **2**:517-520.
- SHEPPARD, C. R. C. 1987. Coral species of the Indian Ocean and adjacent seas: A synonymised compilation and some regional distributional patterns. *Atoll Research Bulletin* **307**:1-32.
- SHEPPARD, C. R. C. 1988. Similar trends, different causes: Responses of corals to stressed environments in Arabian Seas. Pages. *Proceedings of the VIth International Coral Reef Symposium, Townsville*. **3**:297-302
- SZMANT, A. M., AND N. J. GASSMAN. 1990. The effects of prolonged bleaching on the tissue biomass and reproduction of the reef coral *Montastrea annularis*. *Coral Reefs* **8** (4):217-224.
- THANGAL, A. P. A., editor. 1994. Basic statistics 1993-94: Union territory of Lakshadweep. Department of Planning and Statistics, Kavaratti.
- WILLIAMS, E. J. J., AND L. BUNKLEY WILLIAMS. 1990. The world wide coral reef bleaching cycle and related sources of coral mortality. *Atoll Research Bulletin*:335.

TABLES AND GRAPHS

	Gulf of Kutch (n = 7)		Lakshadweep (n = 34)		Gulf of Mannar (n = 30)	
	Mean	SEM	Mean	SEM	Mean	SEM
Coral Cover	11.7	3.22	37.2	1.99	33.6	3.21
Turfed Coral	41.4	4.55	21.4	2.16	32.0	2.73
Coralline & Calcerous Algae	5.1	1.76	14.9	1.02	10.3	1.02
Fleshy Algae	15.5	3.31	0.0	0.00	5.7	1.91
Seagrass	0.0	0.01	0.2	0.21	0.0	0.00
Other Invertebrates	7.6	3.07	0.4	0.15	0.5	0.19
Sand	18.8	2.97	18.9	2.55	11.0	2.89
Rubble	0.0	0.00	7.0	1.23	6.9	1.77

Table 1. Percent composition of reef benthic substrate in the Gulf of Kutch, Lakshadweep and Gulf of Mannar. The Gulf of Kutch data was collected using multiple 1m² quadrats. The Lakshadweep and Mannar data were collected along 10m point intercept transects.

	Anomaly Days	Pale (%)	Bleached (%)	Dead (%)	Total Affected
Gulf of Kutch	0	8.81	1.92	0	10.73
Lakshadweep	78	26.0	30.09	25.71	81.80
Gulf of Mannar	99	24.98	41.26	23.00	89.24

Table 2. Percent cover of stressed and dead coral recorded in the reefs of Kutch, Lakshadweep, and Mannar. Only coral where the cause of death could unambiguously be assigned to bleaching were included in the Dead Coral category, so as not to overestimate the impact of the bleaching. The anomaly days represent the approximate number of days the studied reef had been exposed to SST's of higher than 1°C, prior to the dates of sampling.

Genus	Lakshadweep	Gulf of Mannar	Gulf of Kutch
Branching <i>Acropora</i>	12.41	6.82	--
Tabular <i>Acropora</i>	0.90	22.02	--
<i>Astreopora</i>	1.15	--	1.77
<i>Cyphastrea</i>	2.71	0.31	2.04
<i>Favia</i>	--	5.03	4.74
<i>Favites</i>	1.45	0.91	24.59
<i>Fungia</i>	0.24	--	--
<i>Galaxea</i>	0.46	--	--
<i>Gardinerorseris</i>	0.76	--	--
<i>Goniastrea</i>	0.41	0.42	--
<i>Goniopora</i>	0.15	--	12.77
<i>Hydnophora</i>	--	0.84	1.23
<i>Leptastrea</i>	0.71	--	--
<i>Millepora</i>	1.48	--	--
<i>Montipora</i>	4.31	35.77	2.64
<i>Mycedium</i>	0.08	--	--
<i>Pavona</i>	10.94	--	--
<i>Platygyra</i>	0.46	--	18.03
<i>Pocillopora</i>	1.44	3.55	--
<i>Porites</i>	57.95	14.51	23.91
<i>Stylophora</i>	1.99	--	--
<i>Symphyllia</i>	--	0.33	5.27
<i>Turbinaria</i>	--	9.47	3.02

Table 3. Percent composition of coral genera in the Lakshadweep, Gulf of Mannar and Gulf of Kutch.

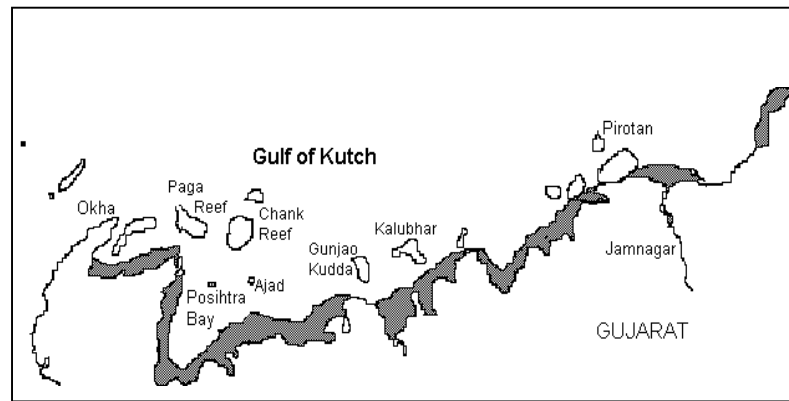


Figure 1. The southern Gulf of Kutch, Gujarat, India. The extensive grey areas represent mudflats and degraded mangroves.

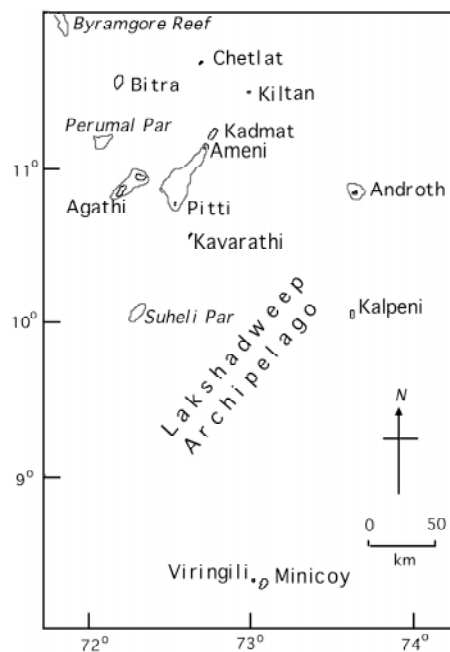


Figure 2. The islands of the Lakshadweep and Minicoy Archipelago, Indian Ocean

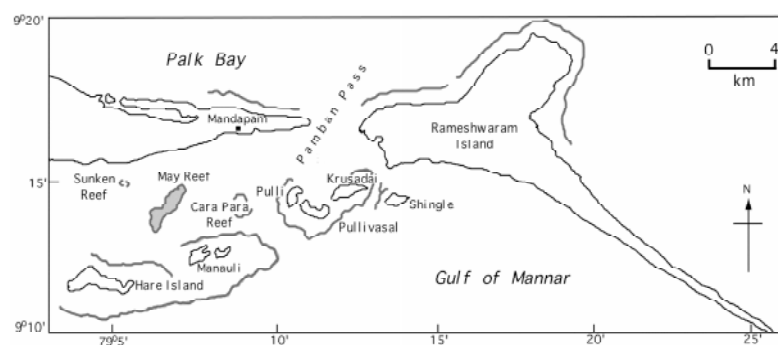
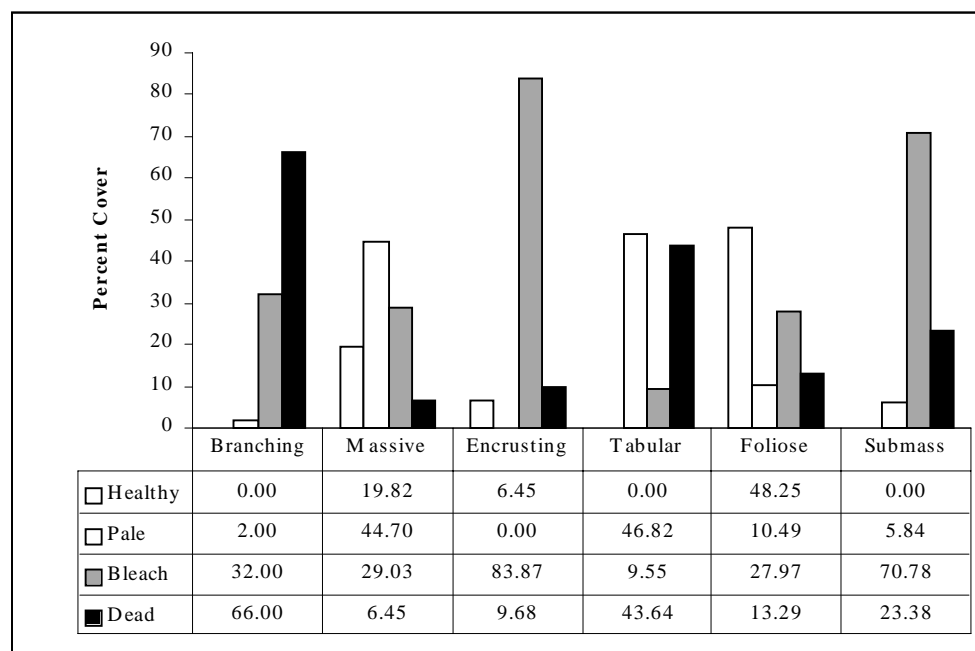
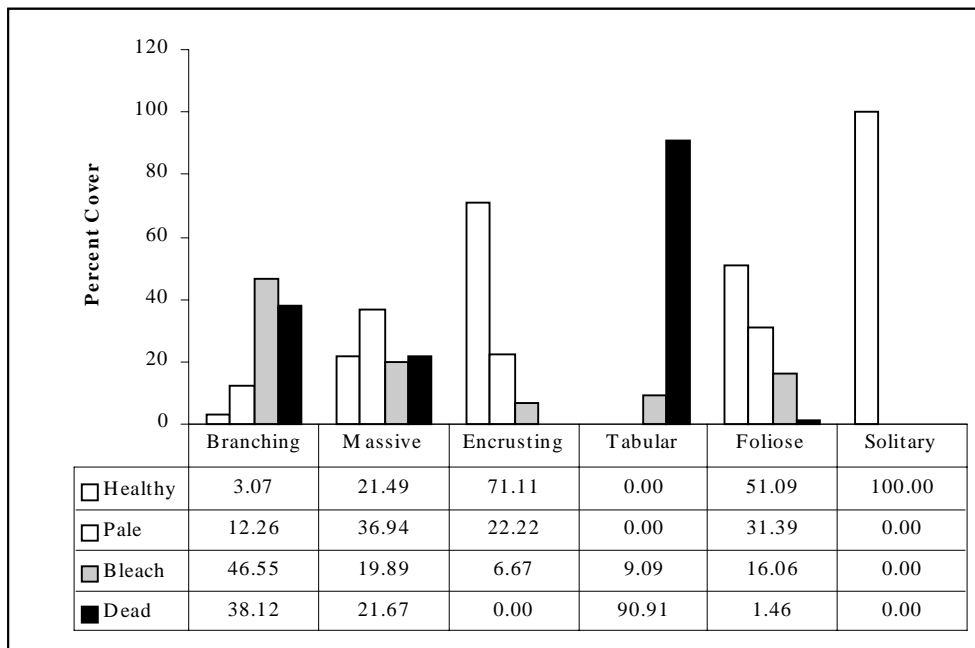


Figure 3. The islands of the Gulf of Mannar and Palk Bay

a. Lakshadweep Islands



b. Gulf of Mannar

Figure 4. Coral lifeforms, showing differential stress responses to bleaching.